Design and Preliminary Feasibility Study of a Soft-Robotic Glove for Hand Function Assistance in Stroke Survivors

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A gloomy trend...

Increasing average age

due to increased life expectation and only few newborns in most of the western countries

Shortage of specialists

and of places in the structures that won't be able to follow the biological need

Poor quality treatments

for people who can not afford private health care

… and the most *handy* solution

Robotic aided at-home therapy

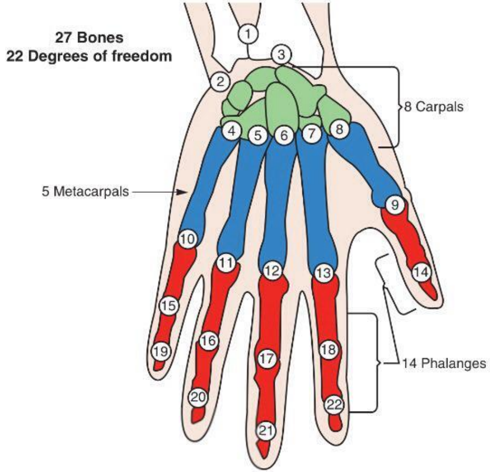
- More comfortable than being in an hospital
- Relatively cheap to implement and accessible to patients
- Easy to use: doesn't require continuous supervising

Example: soft robotics for rehabilitation

In particular we want to address the **hand rehabilitation** for stroke survivors.

The hand is a complex mechanism and supporting it with rigid structures would result in many links and actuators, too heavy and rigid for daily life activities.

Soft robotics solves this problem in a completely different way.



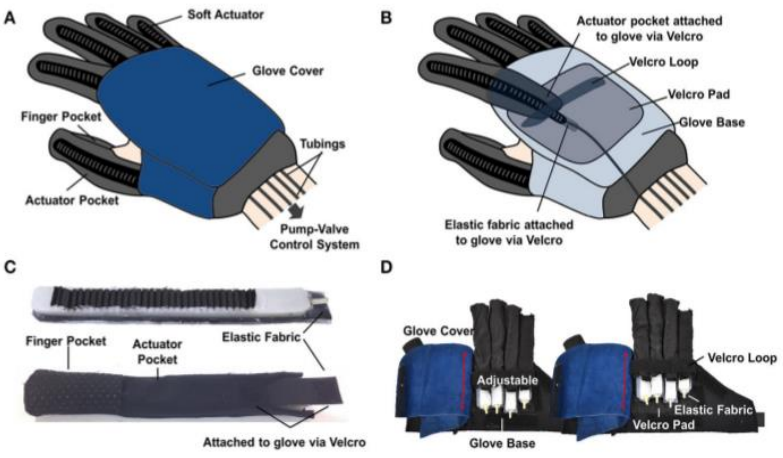
Design criteria

Project's specific goal: help stroke survivors cope with Activities of Daily Life by improving **manipulation of objects of daily living.**

1. Weight: The glove, with its 180g of weight on the hand, and the whole structure, with its 1.5kg of total weight, stay well below the threshold for acceptable weight of a device on the human hand (400-500g on the hand itself and 3kg of total weight)
2. Setup time: it must be used by patients with different hand sizes and with little help and supervision from physiotherapists
3. Efficient grasping: performed with a pneumatic actuation to be put on the outer side of the hand.

Structure

- Five finger-actuator **pockets**, made from lycra fabrics, attached on the dorsal side via Velcro.
- A **wrist strap** helps securing the glove to the wrist.
- The glove has a total **weight** of 180g and a **thickness** of 2 cm.
- The inflation does not add a significant amount of extra weight.



Actuation

- ## Actuator Design

The glove has soft fabric-reinforced **pneumatic actuators** with a *corrugated top fabric layer* and a *single elastic layer* with higher elastic modulus on the bottom. (Fig. A).

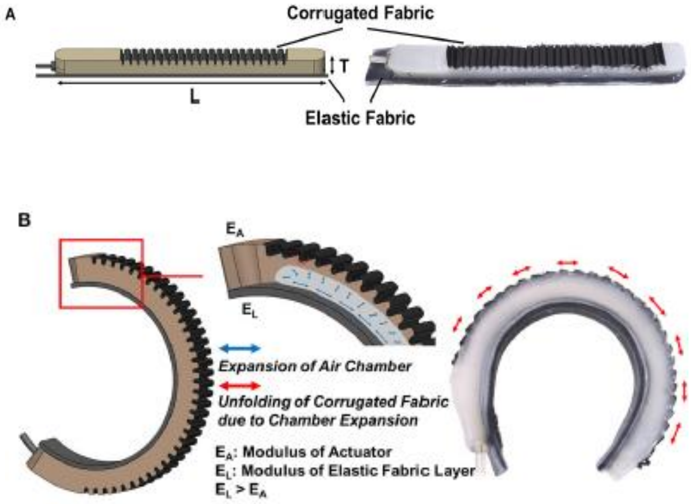
To obtain bending capability: the corrugated layer on the top will expand while the elastic layer on the bottom elongates and stores elastic energy. (Fig. B).

- ## Actuator Fabrication

A 3D-printer is used to fabricate it.

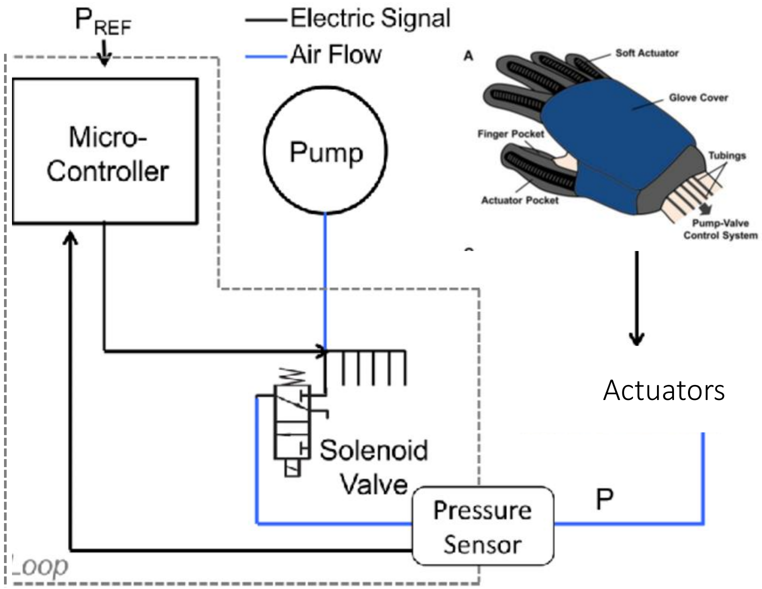
- ## Actuator Characterization

The actuators are characterized in terms of their *blocked tip force* and *grip force* upon pressurization.



Pump-valve control system

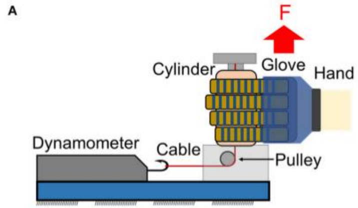
- **On/off** regulation **valve** that regulates through a micro-controller the air pressure measured by the sensors.
- **Control algorithm**: PID - stable and accurate.
  Pref = 120kPa as result of ROM test - full finger flexion.
- Fully integrated, portable and non invasive.
- Miniature architecture repeated for each finger.



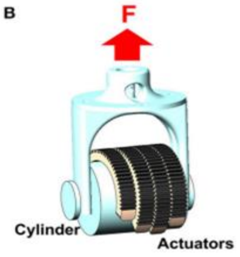
Preliminary tests on healthy people

- **Goal**: determine the grip strength (A) ,normal (B) and frictional (C) grip forces when resisting the upward motion of a cylinder.

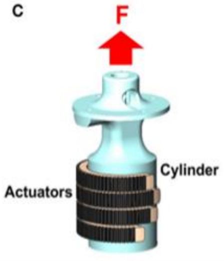
  5 participants: 3 males, 2 females, age: 26.2 ± 2.4y.



- The **normal grip force** is the sum of the normal forces applied by actuators to the cylinder surface. The measured force was that resisting the upward motion of the cylinder.



- The **frictional grip force** is the force exerted by the actuators as the cylinder moves and slides across them.



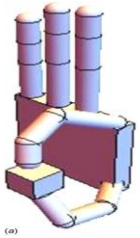
Preliminary tests on healthy people

- **Goal**: determine the ROM of individual finger joints and grip strength.
  5 participants: 3 males, 2 females, age: 26.2 ± 2.4y.

- **Active trials:** participants were instructed to close and open their right hand with the presence of the glove.

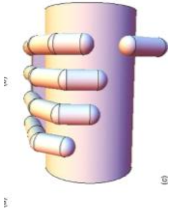
- **Glove-assisted trials:** the participants relax their muscles. Open/close action is assisted by soft actuators. EMG signals are recorded to verify the authenticity of the voluntary control.

Results on healthy subjects



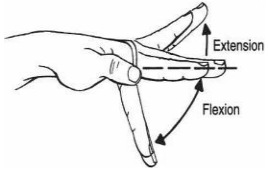
Tip force force

- Maximum tip force of 9.12 N at 120 kPa



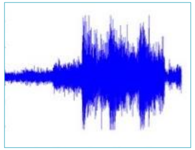
Grip force

- Normal and frictional grip forces decrease with decreased cylinder diameter. As the objects of daily living do not weigh more than 1.5 kg, the frictional force was found to be sufficient to lift most of the objects.



Range of motion of the fingers

- Active trials: sum of fingers joint angles: ~211.
- Glove-assisted trials: sums of finger joint angles: ~200.



EMG signals

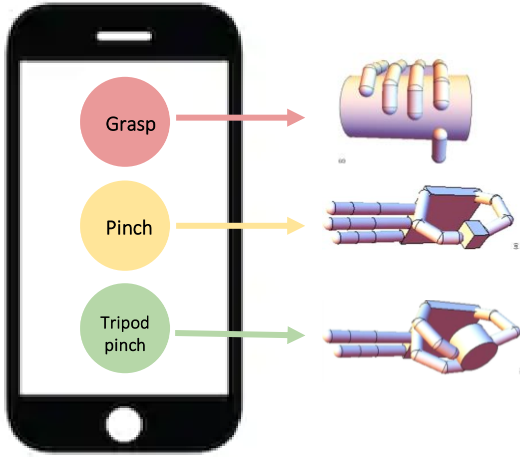
- During the glove-assisted trials, EMG signal confirmed that the participants exerted minimal muscle effort: hand closing and opening motions were completely assisted by the glove.

Pilot tests on stroke survivors

- **Goal**: perform activities of daily life (grasp an empty water bottle and a tin can) with and without the glove.
  2 partecipants.

- The task was considered successful if the patient was able to grasp, lift, and put down the object. The participants were allowed to use their non-paretic hand to support their paretic forearm if they could not lift their paretic arm.

- Patients had to click three virtual buttons on a smartphone application using their non-paretic hand. To deactivate the glove, the patients just simply clicked the specific activated button again.



Results: test with stroke survivors

Without the glove, patient 1 couldn't effectively grasp the water.
Average time to finish the tasks: 9 s.

With the assistance of the glove: patient 1 could finish all the tasks.
Average time: 8 s.

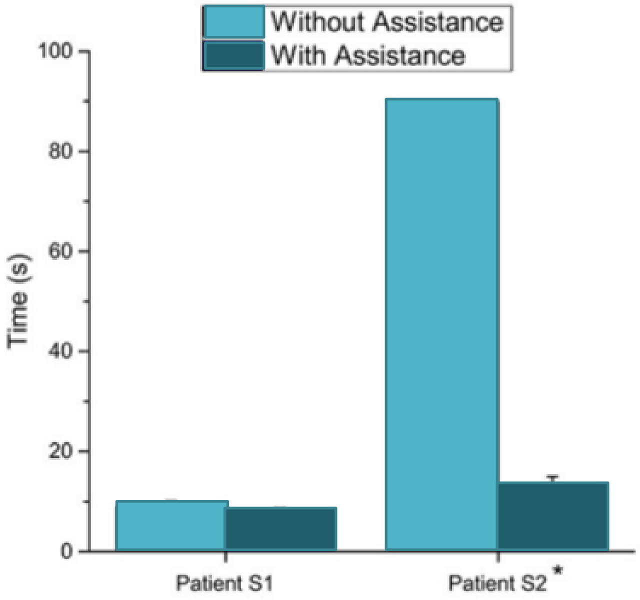
Patient S1

Without the glove, patient 2 could not finish the tasks within 90 s and he could grasp none of the objects.

With the assistance of the glove: patient 2 could finish all the tasks.
Average time: 12.3s.

Patient S2

Results: test with stroke survivors



Statistically not significant in terms of time…

… but practically very useful in daily life activities!

Results: questionnaire

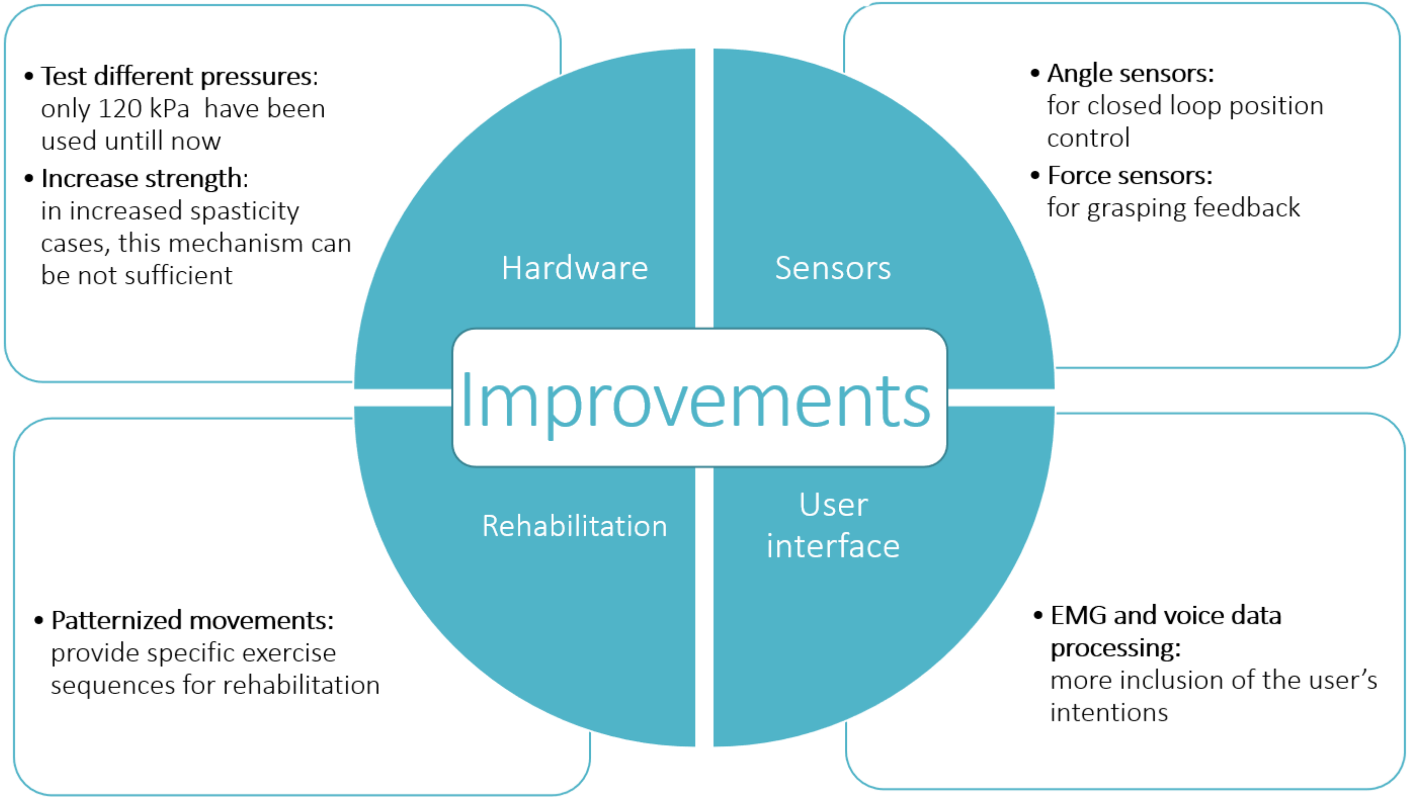
After the test, patients were instructed to fill in the Usefulness - Satisfaction - and - Ease - of - use questionnaire and a questionnaire focusing on comfort level, desire to use, and desire to purchase the device. Generally, the patients reported scale of at least five out of seven-point rating.

Parameters	**Mean (SD)**
USE QUESTIONNAIRES	
Usefulness	5.9 ± 0.3
Ease of use	6.4 ± 0.4
Ease of learning	6.6 ± 0.2
Satisfaction	6.6 ± 0.5
PATIENTS' FEEDBACK	
Comfort level	6.0 ± 1.4
Desire to use	6.5 ± 0.7
Desire to purchase	5.0 ± 1.4

SD, standard deviation.

Conclusions

- **Structure**
  - Comfortable
  - Light weight
- **Actuation**
  - Less power consumption
  - On/off control
- **Implementation**
  - Cheap
  - Little setup time
- **Usage**
  - Easy to adapt glove
  - User-friendly app
- **Psychological effect**
  - Motivation to exercise
  - Improved mood


Improvements
Hardware
Sensors
Rehabilitation
User interface
• **Test different pressures:** only 120 kPa have been used untill now
• **Increase strength:** in increased spasticity cases, this mechanism can be not sufficient
• **Angle sensors:** for closed loop position control
• **Force sensors:** for grasping feedback
• **Patternized movements:** provide specific exercise sequences for rehabilitation
• **EMG and voice data processing:** more inclusion of the user's intentions